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ORIGINAL PAPER

Effect of canopy gap size and ecological factors on species diversity and beech seedlings in managed beech stands in Hyrcanian forests

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Abstract: We studied the species diversity of the herb layer and ecological factors in harvest-created gaps in beech stands under a single-tree selection system in Northern Iran. To determine diversity, the number of beech seedlings, and other ecological factors, 16 gaps were selected and subplots of 5 m^2 were positioned at the centre and at the cardinal points of each gap. Species richness and Simpson diversity index increased with increasing gap area as did numbers of seedlings. With increasing humus layer thickness, species richness declined but the Hill evenness index increased. Species richness increased with increasing light availability. There was no relationship between crown radii of beech trees and diversity indices. Correlations between environmental factors and numbers of individuals of some species in the herb layer were not significant except in a few cases. The results help explain the effects of man-made gaps on the dynamics of managed beech stands and this benefits evaluation of silvicultural operating plans.

Keywords: beech; gap; herbaceous species; diversity; Hyrcanian forests

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Introduction

Biodiversity is necessary for human endurance, economic well-being, and ecosystem function and stability (Singh, 2002). Biodiversity preservation is considered to be a key management objective which is essential for sustainable forestry (Torras et al. 2008) and has been perceived as a fundamental element for estimating vegetation restoration (Zhu et al. 2009). Apart from being economically important, forests are highly valued as natural ecosystems and their biodiversity preservation, consequently, has arisen as one of the main objects of forest management (Pitkänen 2000).

Disturbance of the forest canopy can result in changes in the abundance and richness of understory plant species (North et al. 2005). Harvesting is recognized as a disturbance of the forest ecosystem (Qiu et al. 2006). Silvicultural operations cause disturbances on large spatial scales (Peltzer et al. 2000; Zhu et al. 2007). Timber harvesting or other silvicultural operations can improve tree regeneration, and may alter biodiversity patterns as well (Elliot et al. 2005). Changes in biodiversity patterns can be explained by the frequency, intensity, and nature of these disturbances (Pre´vosto et al. 2010). Understanding the impact of harvesting operations on species composition is important for sustainable forestry management (Qiu et al. 2006).

Logging can create canopy gaps within forests (Kukkonen et al. 2008). Canopy gaps are formed by the loss of major parts of a tree crown (Abd et al. 2010) and can be the outcome of natural tree falls or harvesting (Zhao et al. 2006; Blair et al. 2010).

Physical and biological environmental changes occur in the forest after canopy gaps develop (Zhao et al. 2006). The ground-layer plant species are intensely vulnerable to environmental conditions (Kern et al. 2006). Reactions of understory herbs have been investigated in relation to clear-cutting (Gilliam et al. 1995; Pykälä 2004), shelter wood (Nagaike et al. 1999; Elliot et al. 2005; Poorbabaei et al. 2009), and selection method (Battles 2001; Falk et al. 2008).

The effect of canopy gaps on plant diversity was studied by Shumann et al. (2003) who reported that harvest-created gaps led to higher species richness in the understory (vegetation <1 m tall) than did controls in Maine oak-pine forest. Zhao et al. (2006) reported significant differences in tree species diversity between gap sizes and under canopy in broad-leaved and Korean pine (*Pinus koraiensis*) mixed forests. Naaf et al. (2007) showed that species number increased with gap size and light availability in European beech (*Fagus sylvatica*) forests.

Menges et al. (2008) showed that herbaceous plant diversity (H', Shannon's index) increased with increasing gap area in Florida rosemary scrub sites. According to Nowińska (2010), differences of gap area had greater affect on herb layer vegetation in oak-hornbeam forest than in oak-pine forest. So far, the relation between canopy gaps and plant species diversity and distribution in the forest of Northern Iran has not been studied. The purpose of the present study was to better understand the effect of harvest-created gaps on herbaceous species diversity in Hyrcanian forests in northern Iran.

The Hyrcanian forests contain broadleaf and conifer mixed forestry species (Banj et al. 2010) with more than 80 species of broadleaf trees and shrubs, of which beech has the highest industrial and commercial value (Pourmajidian et al. 2009). Different silvicultural methods have been applied to create gaps of various sizes in the forest canopy. We investigated the effect of different gap size on species diversity in different silvicultural methods (selecting artificial gaps and single-tree selection method) in beech stands (*Fagus orientalis* Lipsky) in 2000. We sought answers to the following questions: (1) Is there a relationship between ecological factors- light, humus layer thickness, gap size, the number of seedlings- and the diversity of herbaceous species within gaps in beech stands? (2) Is there a relationship between these factors and the crown radii of trees encircling the gaps and the speciation of herb layer species in beech stands?

Materials and methods

Study area

The study area was located in the beech forest of Alandan district (36°13'–36°12' N, 53°23'–53°03' E) in northern Iran, Sari. The study area covered 113 ha and extended in the western aspect between 1,300–1,610 m a.s.l. The forest was dominated by uneven-aged beech. Other less frequent species in this forest were hornbeam (*Carpinus betulus*), maple (*Acer insigne*) and alder (*Alnus subcordata*). The soil parent material was limestone and dolomitic limestone, of the upper Jurassic and lower Cretaceous periods. The soil type was forest brown with suitable penetration and biological activities. The mean annual temperature, rainfall and relative humidity were 10.5°C, 858 mm and 75.2%, respectively. The climate was humid based on the Domarten method.

Study method

We selected 16 canopy gaps to investigate diversity indices in harvest-created gaps by the single-tree selection method removing individual trees or small group of trees in across area (Jones et al. 2009) in 2000. These gaps were located on slopes of westerly aspect and 30% incline. The area of expanded gaps was calculated by measuring the long and short axes as for an ellipse (Runkle 1981). The gap areas ranged from 60 m^2 to 550 m^2. To determine the diversity of herbaceous plants, subplots of 2.5 m × 2.5 m (Chiarucci et al. 2008) were sampled (n = 80). To estimate the regeneration quantity of beech (less than 130 cm height), circular subplots of 5 m^2 (Dobrowolska et al. 2008) were sampled (n=80). These subplots were located in the central part of the gap and its cardinal points.

$$D = 1 - \sum_{i=1}^{s} P_i^2 \tag{1}$$

$$E_5 = (1/\lambda - 1)/(e^{H'} - 1) \tag{2}$$

where, D is the diversity index; P_i is the proportion of individuals in ith species, λ is Simpson's diversity index, H' is Shannon's index and E_5 is Hill's evenness index.

In each subplot, humus layer thickness was measured by ruler. Light conditions were estimated using LI-250A photometric sensor (Licor, Nebraska, USA) at 1.00 m above the ground (Pritchard et al. 2004; Albanesi et al. 2005) at 1,000-1,400 hours on a sunny day (Romell et al. 2009) in July 2009. The number of beech seedlings was counted in each subplot. We measured crown radii of the trees surrounding and facing toward each gap. All the fieldwork was performed during spring and early summer of 2009. We describe the research canopy gaps on a gradient from small to large size (Table 1).

Statistical analysis

We applied Pearson's rank correlation analysis to examine relationships between species diversity and the measured environmental variables. All statistical analyses were used the statistical package SPSS version 18. The level of significance of statistic tests were as follows: $p < 0.05$; $p < 0.01$; $p > 0.05$.

Results

We found a total of 33 herb species beneath 16 canopy gaps (Table 2). Species richness (SR) varied from 8 to 16 between gaps (Table 1). The life form of these species is shown in Fig 1. SR was positively and significantly correlated with light and number of seedlings. SR was negatively correlated with humus layer thickness (Table 3). SR was not significantly correlated with crown radii of trees surrounding canopy gaps. Diversity of the herb layer was positively correlated with number of seedlings (Table 3). Herb-layer evenness was not significantly correlated with light, but was positively correlated with humus layer thickness (Table 3). Herb layer evenness was not significantly correlated with number of seedlings or crown radii (Table 3). Gap area

was significantly and positively correlated with herbaceous species richness and diversity (Table 3). Relationships between environmental factors (light, number of seedlings, humus thickness and crown) and herb layer species was different within gaps (Table 4). Except for *Rubus hyrcanus*, the number of seedlings, crown radii and humus layer thickness for *Viola alba*, *Dryoptris filixmas,* and *Mercurialis perennis* were positively and significantly correlated with light. The correlations between the individual herbaceous species and the factors mentioned above were not significant.

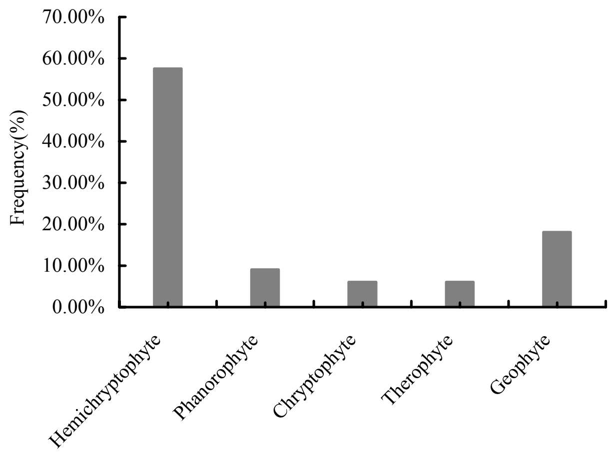

Fig. 1 Life form of herb layer species

Table 1. Diversity indices and environmental factors within 16 artificial gaps in beech stand

Gap	Species richness (n)	Diversity	Evenness	Light (lux)	Crown radii (m)	Number of seedling (ha^{-1})	Humus layer thickness (cm)
1	8	0.548	0.46	3560	4.12	728	1.7
2	11	0.725	0.38	3676	4.13	4513	2.4
3	11	0.663	0.372	1309	3	953	2.3
4	13	0.607	0.277	4263	2.5	606	1.8
5	14	0.696	0.309	1503	4.25	26	1.1
6	14	0.626	0.34	1366	6.63	2133	3
7	11	0.685	0.427	691	4.13	2123	1.9
8	11	0.641	0.439	1988	5.63	1206	3
9	13	0.631	0.296	2949	5	1143	1.7
10	10	0.726	0.892	3398	4.87	225	2.8
11	13	0.799	0.398	3476	4.88	0	2.7
12	12	0.673	0.432	2410	5.25	70	0.5
13	13	0.778	0.483	4462	4.75	735	2
14	15	0.798	0.321	3294	5.25	915	0.8
15	13	0.752	0.337	2917	5.13	50	1.1
16	16	0.753	0.275	3522	4.88	424	1.6

Table 2. Herb layer species within artificial gaps in beech stand

Herb species	Family	Life form	Gap class S	M	L	VL
Brachypodium sylvaticum	Graminae	He	+	+	*	*
Calystegia sepium	Convolvulaceae	He	*	*	*	+
Campanula rapunculus.	Campanulaceae	He	*	*	+	*
Cardamine impatiens	Cruciferae	He	+	+	+	+
Carex pendula	Cyperaceae	He	*	+	+	*
Carex sylvatica	Cyperaceae	He	+	+	*	+
Cephalenthera longifolia	Orchidaceae	Ge	+	+	*	+
Circaea lutetiana L.	Onagraceae	He	+	+	+	+
Cyclamen coum	Primulaceae	Ge	+	*	+	*
Dryoptris filix-mas	Aspidiaceae	Ge	+	+	*	+
Euphorbia amygdaloides	Euphorbiaceae	Ch	+	+	+	+
Fragaria vesca L.	Rosaceae	He	+	+	*	+
Galium odoratum	Rubiaceae	He	+	+	+	+
Geranium montanum	Geraniaceae	He	+	+	*	*
Hesperis hyrcana.	Cruciferae	He	+	+	*	*
Hypericum androsaemum	Hypericaceae	Ch	*	+	+	+
Lamium album	Labiatae	He	+	+	+	+
Lathyrus Laevigatus.	Papilionaceae	Th	+	+	+	+
Mercurialis perennis	Euphorbiaceae	He	*	+	+	+
Oplismenus undulatifolius	Graminae	Th	*	+	+	*
Phylitis scolopendrium	Aspleniaceae	He	+	*	+	+
Polygonatum orientale	Liliaceae	Ge	+	+	+	*
Polystichum aculeatum	Aspidiaceae	Ge	+	+	*	+
Primula heterochroma	Primulaceae	He	*	+	*	+
Pteris cretica.	Pteridaceae	Ge	*	*	+	+
Rubus hyrcanus	Rosaceae	Ph	+	+	+	+
Ruscus hyrcanus	Liliacea	Ph	+	+	+	+
Rhynchochoris elephas	Scrophulariaceae	He	*	*	*	+
Solanum dulcamara	Solanaceae	Ph	+	+	+	+
Sanicula europaea	Umbelliferae	He	*	*	+	+
Vincetoxicum scandens	Asclepiadaceae	He	+	+	*	*
Viola alba	Violaceae	He	+	+	+	+
Urtica dioica	Urticaceae	He	+	+	+	*

Notes: S is Small, M is Medium, L is Larege, VL is very large, + is present, * is absent, Ph is Phanorophyte, Ge is Geophyte, Th is Therophyte, He is Hemichryptophyte, Ch is Chryptophyte.

Table 3. Correlation between diversity indices and environmental parameters

Factor	Species richness(SR)	Simpson's index	Hill's index
Light(Lux)			
r	0.23^{*}	-0.07^{ns}	-0.08^{ns}
P-value	0.044	0.558	0.525
Number of seedling(n/ha)			
r	0.29^{**}	0.23^{*}	-0.19^{ns}
P-value	0.008	0.04	0.094
Crown radii(m)			
r	-0.03^{ns}	0.06^{ns}	-0.05^{ns}
P-value	0.805	0.631	0.964
Humus layer thickness(cm)			
r	-0.26*	-0.24^{ns}	0.25^{*}
P-value	0.027	0.065	0.031
Gap area(m^2)			
r	0.57^{*}	0.70^{**}	0.02^{ns}
P-value	0.023	0.002	0.951

Notes: * stands for $P < 0.05$; ** stands for $p < 0.01$; ns is no significance.

Table 4. Correlation of herb layer species individuals and ecological factors

Factor		*Mercurialis perennis*	*Galium odoratum*	*Lamium album*	*Rubus hyrcanus*	*Viola alba*	*Dryoptris filix-mas*	*Solanum dulcamara*
Light	*r*	-0.12/ ns	-0.41/ ns	-0.001/ ns	0.29/*	0.06/ ns	0.11/ ns	-0.09/ ns
	P-value	0.330	0.719	0.993	0.01	0.610	0.365	0.411
No. of seedling (n/ha)	*r*	-0.15 /ns	0.25/*	-0.07/ ns	-0.18/ ns	0.27/*	0.13/ ns	0.12/ ns
	P-value	0.210	0.029	.0.565	0.117	0.019	0.261	0.342
Crown radii (m)	*r*	-0.13/ ns	0.02/ ns	-0.06 /ns	0.100/ ns	0.18/ ns	0.25/*	-0.17/ ns
	P-value	0.298	0.867	0.653	0.432	0.167	0.049	0.173
Humus layer thickness (cm)	*r*	0.27/*	-0.21/ ns	0.05/ ns	-0.03/ ns	0.08/ ns	-0.08/ ns	0.001/ ns
	P-value	0.019	0.063	0.655	0.825	0.458	0.482	0.991

Notes: * stands for $p < 0.05$; ns is no significance.

Discussion

Since understory plant species account for most plant diversity in temperate forests, it is important for forest managers to determine the factors affecting distribution of these plants (Gracia et al. 2007) and maintain understory plant diversity in regard to harvesting (Ellum et al. 2010).

Our study showed that species richness increased with gap area, which is consistent with findings of other researchers (Kimberly et al. 2002; Ga´lhidy et al. 2006; Naaf et al. 2007; Falk et al. 2008; Menges et al. 2008). Most species beneath gaps were represented by few individuals (Sapkota et al. 2009). The similar result was also obtained by this study. *Galium odoratum*, *Solanum dulcamara*, *Mercurialis perennis*, *Viola alba*, *Lamium album*, *Dryoptris filix-mas,* and *Rubus hyrcanus* had the highest number of herbaceous species beneath gaps. The typical life form within gaps is hemichryptophytes (Fig. 1). Mölder et al. (2008) observed that these species have better capability to survive in severe the environmental conditions (especially light) in beech forest. The presence of herb species *Calystegia sepium*, *Campanula rapunculus*, *Sanicula europaea, Rhynchochoris elephas*, *Pteris cretica* within larger gaps and *Brachypodium sylvaticum*, *Hesperis hyrcana*, *Vincetoxicum scandens* beneath smaller gaps can be attributed to light conditions. Barbier et al. (2008) believed that understory plant species have different optimal light requirements.

Gap size affected species diversity and the species richness of the herb layer, although differences in species richness among gaps were not considerable. Miho´k et al. (2007) concluded that there was a positive correlation between herb layer coverage and canopy gaps. This study shows that in spite of compositional similarities in overstory tree species (only beech) at the edges of gaps, variation in light intensity affected understory herbs.

Naaf et al. (2007) stated that the increase in species richness beneath gaps is mainly due to larger space and higher light availability (Table 3). Ha¨rdtle et al. (2003) believed that many species in beech forest have adjusted to adverse light conditions. We found that the number of beech seedlings affects herb species richness and diversity (Table 3) after gap formation. Increased light intensity increased the number of seedlings. As Bullock (2000) stated an increase in the number of beech seedlings with increasing herb species richness can be due to the decrease in competition for one or more resources (e.g. light, nutrients and water) in forest gaps. *Mercurialis perennis* is a rhizomatous perennial herb (Masarovičová and Eliáŝ. 1985), and very tolerant to low light (Jefferson 2008) influenced by chemical and physical features of the soil and humus characteristics (Van et al. 2005). This negative effect may be somehow related to the physical impact of litter thickness (Sydes et al. 1981b). Ground flora species vary in terms of their ability to penetrate into litter (Sydes et al. 1981a). The abundance of *Galium odoratum*, a perennial rhizomatous plant of deciduous forests (Andersson 1992), is correlated with the number of beech seedlings (Bullock 2000). *Mercurialis perennis* and *Galium odoratum* are indicators of suitable moisture, mild temperature, and high N in beech stands (Abrari et al. 2002). Eshaghi et al. (2009) indicated that *Mercurialis perennis* and *Ruscus hyrcanus* are indicators of high fertility in beech forests.

Rubus hyrcanus is a light-demanding species (Degen et al. 2005). The number of *Rubus hyrcanus* was positively correlated with light intensity (Table 4). The numbers of some herb species were negatively correlated with environmental factors due to different microclimate conditions within gaps.

We believe that an eight-year span in single-tree selection method may provide adequate time for development of understory plant communities within gaps while also minimizing disturbance to the forest. Our results show that there is positive (such as light and gap area to species richness) and as well negative (such as humus thickness to species richness) correlation between some variables in harvest-created gap under single-tree selection method in a managed beech stand. Gap size is an important factor in determining the relationship between physical and biological components and herbaceous plant diversity in the present logged forest. The result of the study suggests that gap size should be taken into consideration in applying different silvicultural methods, especially selection method for biodiversity maintenance. Observing herb layer species in gaps may help forest managers to estimate the stand changes after harvesting operations.

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